In-Space Manufacturing Project (prior to FY15: Additive Manufacturing Technology Development) (ISM)

Completed Technology Project (2012 - 2018)

Project Introduction

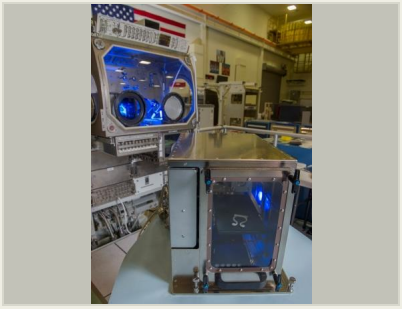
The In-Space Manufacturing (ISM) project is responsible for developing the manufacturing capabilities that will provide on-demand, sustainable operations during NASA Exploration Missions (in-transit and on-surface). This includes testing & advancing the desired technologies, as well as establishing the required skills & processes for the processes (such as certification and characterization) that will enable the technologies to become institutionalized.

The key capabilities being developed in ISM to support this "make it, don't take it" approach include developing a 3D printing Fabrication Laboratory ('FabLab') that can manufacture parts in space using multiple materials, as well as the ability to embed printed electronics, in-space recycling of printed parts and other materials such as packaging in order to reduce mass and waste, and manufacturing structures externally in space. In 2015, the ISM project made history by sending the first 3D printer to ISS and manufacturing the first parts ever in space. This was a critical first step in demonstrating additive manufacturing in microgravity.

Note: Prior to FY15, this project was named the Additive Manufacturing Technology Development project.

Long-term mission objectives require a dramatic paradigm shift in the design and development of space architectures. An analysis of the Problem Reporting and Corrective Action System for failures on the ISS revealed that 88% of those failures could have been remedied and hardware put quickly back into operation with on-board fabrication and repair technologies. ISM offers an elegant solution for sustainability and affordability by identifying and developing on-demand processes, such as additive manufacturing, to address the in-space construction, repair, and maintenance of vehicles, critical systems, habitats, and uncrewed spacecraft for long-duration missions (both in-transit and on-surface). These capabilities, along with the optimum use of recycled and in situ materials, provide meaningful mission cost savings due to reducing launch mass, as well as significant risk reduction due to decreasing dependence on spares and/or over-designing systems for reliability. Objectives will be met through the demonstration of periodic, evolving technology demonstrations in space environments.

To truly develop the capabilities needed for the first long-duration exploration missions, ISM is generating the requirements for an integrated multi-material Fabrication Laboratory ('Fab Lab') that will be capable of manufacturing multi-material parts with embedded electronics, autonomous operations, inspection capability, and optimized performance for volume, accuracy, repeatability, etc. The first generation Fab Lab will be a rack facility on the ISS competed via a Broad Agency Announcement (BAA) in 2017. Near-term objectives that inform the requirement development include continued operations of the 3D Printer Tech Demo (Small Business Innovation and Research (SBIR)) onboard



3D Printing in Space Test on the International Space Station (ISS)

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the ISS, use of a commercial Additive Manufacturing Facility (AMF) printer (also SBIR and CASIS) scheduled to be delivered to the ISS in FY16, and the characterization of ground and space-printed parts to determine microgravity effects, if any. Other FY16 work includes the development of an in-space recycler demonstration for the ISS in FY17 (via SBIR) and multiple SBIRs to identify and evaluate common-use materials that can initially serve as packaging and stowage materials, then be recycled into raw feedstock for the additive manufacturing of new parts.

These new 3-D printing technologies will provide the capability to produce hardware on-demand, directly lowering costs and decreasing risk by having the exact part or tool needed in the time it takes to print. This capability will also provide the much-needed solution to the cost, volume, and up-mass constraints that prohibit launching everything needed for long-duration or long-distance missions from Earth, including spare parts and replacement systems. This project is the first step towards realizing a "machine shop" in space, which is a critical enabling component of any deep space exploration mission.

Anticipated Benefits

The capability to produce hardware on-demand, using 3D printing technologies, will directly lower cost and decrease risk by having the exact part or tool needed in the time it takes to print. This project is the first step towards realizing a "machine shop" in space that is a critical enabling component of any Deep Space Exploration Mission. Successful development of a material recycler will allow deep-space missions to reuse existing material and require less original feedstock for printed parts. Customers for ISM include NASA deep space missions (Human Exploration and Operations Mission Directorate), specifically the Advanced Exploration Systems Division, the Space Technology Mission Directorate's Game Changing Development Program, and the ISS Program.

There are many savings associated with having an additive manufacturing device available during a mission:

1. Reduced up-mass and volume for spare parts resulting in fewer launches (i.e., decreased cost and schedule to achieve exploration missions).

2. Does not require fabrication, launch, and flight time from Earth for delivery.

3. Production time can be on the order of minutes or hours.

4. Ability to print parts and/or architectures never conceived due to the unique

Organizational Responsibility

Responsible Mission Directorate:

Exploration Systems Development Mission Directorate (ESDMD)

Lead Center / Facility:

Marshall Space Flight Center (MSFC)

Responsible Program:

Exploration Capabilities

Project Management

Program Director:

Christopher L Moore

Project Manager:

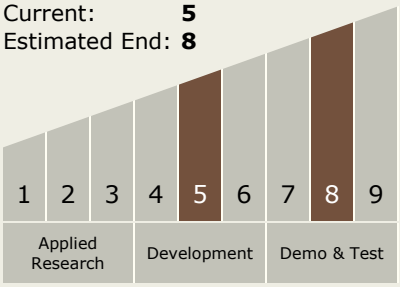
Mary J Werkheiser

Principal Investigator:

Mary J Werkheiser

Technology Maturity (TRL)

Start: **5**
Current: **5**
Estimated End: **8**



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attributes of additive manufacturing and not having to design around launch load constraints.

Customers for ISM include NASA deep space missions (Human Exploration and Operations Mission Directorate) specifically the Advanced Exploration Systems Division, the Space Technology Mission Directorate's Game Changing Development Program, and the ISS Program. There are many savings associated with having an additive manufacturing device available during a mission.

1. Reduced up-mass and volume for spare parts resulting in fewer launches (i.e., decreased cost and schedule to achieve exploration missions).

2. Does not require fabrication, launch, and flight time from Earth for delivery.

3. Production time can be on the order of minutes or hours.

4. Ability to print parts never before conceived to build structures, handle mission critical situations, etc.

The terrestrial commercial market for these technologies is disruptive and evolving quickly. The NASA ISM project utilizes mechanisms such as Small Business Innovation Research (SBIR) awards, Broad Agency Announcements (BAA), Challenges, etc., to work closely with industry in order to leverage these rapid technology advances. This results in stimulating the terrestrial economy in this area, while utilizing the limited NASA resources to focus on adapting these technologies for microgravity applications. Additionally, ISM helped to establish and will be the first government user of the commercial printer that Made in Space, Inc. is launching to ISS thru CASIS.

FY15/16 : Defense Advanced Research Projects Agency (DARPA): The ISM project and Defense Advanced Research Projects Agency (DARPA) are working together to identify technologies that can be utilized for on-demand, external, in space manufacturing and repair. The Air Force is interested in the ability to manufacture small CubeSats in-space, on-demand. The Army and Navy are interested in leveraging the lessons learned for creating high performance, small, safe, on-demand manufacturing facilities for undersea and on-land soldier deployment applications.

Technology Areas

Primary:

- TX12 Materials, Structures, Mechanical Systems, and Manufacturing
  - TX12.4 Manufacturing
    - TX12.4.1 Manufacturing Processes

Target Destinations

Earth, The Moon, Mars

Supported Mission Type

Planned Mission (Pull)

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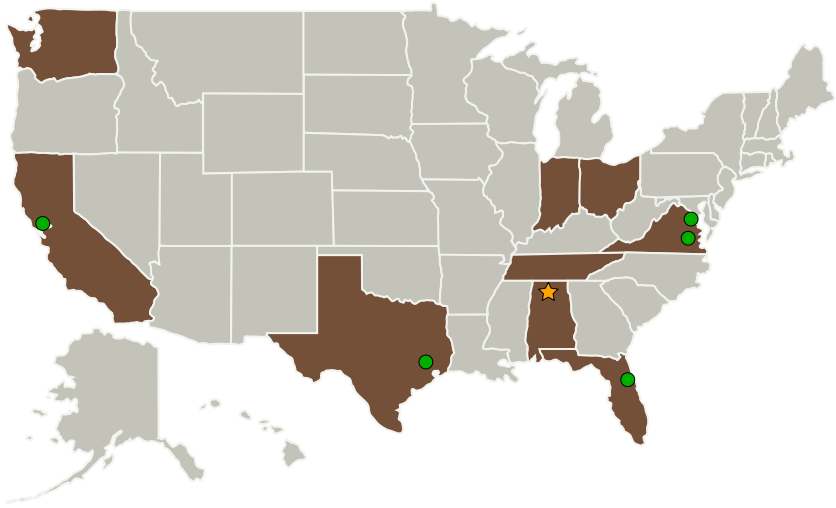
Primary U.S. Work Locations and Key Partners



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Organizations Performing Work	Role	Type	Location
★Marshall Space Flight Center(MSFC)	Lead Organization	NASA Center	Huntsville, Alabama
American Society of Mechanical Engineers	Supporting Organization	Academia	New York City, New York
●Ames Research Center(ARC)	Supporting Organization	NASA Center	Moffett Field, California
Army	Supporting Organization	US Government	Washington, District of Columbia
Army Aviation and Missile Research, Development and Engineering Center(AMRDEC)	Supporting Organization	US Government	Huntsville, Alabama
Cornerstone Research Group, Inc.	Supporting Organization	Industry	Miamisburg, Ohio
Defense Advanced Research Projects Agency(DARPA)	Supporting Organization	US Government	
●Johnson Space Center(JSC)	Supporting Organization	NASA Center	Houston, Texas
●Kennedy Space Center(KSC)	Supporting Organization	NASA Center	Kennedy Space Center, Florida
●Langley Research Center(LaRC)	Supporting Organization	NASA Center	Hampton, Virginia
Made in Space, Inc.	Supporting Organization	Industry	JACKSONVILLE, Florida
●NASA Headquarters(HQ)	Supporting Organization	NASA Center	Washington, District of Columbia
nScrypt, Inc.	Supporting Organization	Industry	Orlando, Florida

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Organizations Performing Work	Role	Type	Location
Oak Ridge National Laboratory(ORNL)	Supporting Organization	R&D Center	Oak Ridge, Tennessee
Optomec Inc	Supporting Organization	Industry	Albuquerque, New Mexico
Techshot, Inc.	Supporting Organization	Industry	Greenville, Indiana
Tethers Unlimited Inc	Supporting Organization	Industry	
Ultratech Machinery	Supporting Organization	Industry	Cuyahoga Falls, Ohio
Vanderbilt University	Supporting Organization	Academia	Nashville, Tennessee

Co-Funding Partners	Type	Location
Exploration Systems Development Mission Directorate(ESDMD)	NASA Mission Directorate	
Space Technology Mission Directorate(STMD)	NASA Mission Directorate	

Primary U.S. Work Locations	
Alabama	California
District of Columbia	Florida
Indiana	Ohio
Tennessee	Texas
Virginia	Washington

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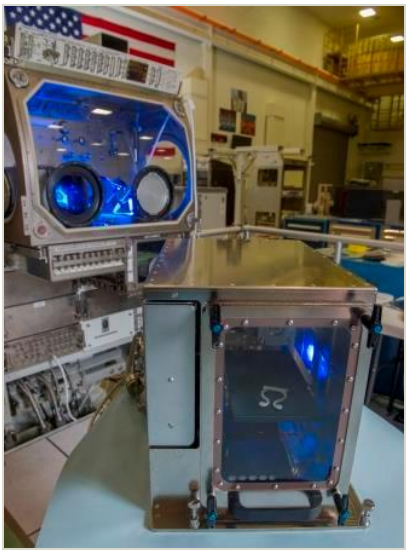
Images



In-Space Manufacturing
3D Printing in Space Test on the International Space Station (ISS)
(https://techport.nasa.gov/image/3462)

Stories

3D Printing on the International Space Station: A Key Step to Pioneering Sustainable Exploration Missions
(https://techport.nasa.gov/file/27010)

Launched the first 3D Printer in space on SpaceX-4 Cargo Mission to ISS on 9/21/14
(https://techport.nasa.gov/file/21914)